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A Cradle-to-Cradle Novel Approach for Wastewater Management in Sustainable Urban Communities

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Abstract

Water, a valuable resource to human lives, is being abused and driven to scarcity. This scarcity is leading some countries and areas to face difficulty in accessing drinking water. As the UN recently stated "by 2050 water shortages and harder access will be reached by around 2/3rd of the world total population" [1], thus, there is a high need to treat and reuse wastewater for domestic purposes, which will lead to less reliance on fresh water as an initial water source. Greywater—defined as the water produced in domestic houses including sinks and bathroom showers, and excluding any blackwater mix which is collected from toilets—is a type of wastewater. Greywater accounts for up to 75% of the daily water produced [2] while it has fewer contaminants when compared to blackwater. This makes greywater a focal point for treatment, and reusing to conserve fresh water and approach net zero water concept. Even though the definition of greywater is the same globally, its criteria can differ from one country to another, from one building to another, or even from the same person's usage along the day. Accordingly, several treatment methods evolved over years aiming at treating the produced greywater for reuse mainly in irrigation and toilet flushing. The objective of this paper is to demonstrate a novel net zero wastewater approach applying cradle-to-cradle concept for urban communities; while also proposing a sustainable greywater treatment technique that is environmentally friendly, cost-effective and socially acceptable.

Keywords

Net Zero Water, Sustainable Urban Communities, Cradle to Cradle for Wastewater Management, Sustainable Greywater Treatment

1. Introduction

Water, the heart of any living organism, accounting for more than 60% of the human body and covering more than 70% of Earth's surface is now considered as a global concern and challenge being driven to scarcity. Water scarcity is a result of improper usage of water as a resource, leading communities and societies to a level of water stress. Water stress is an inadequate supply for their daily needs [3] and this is witnessed through the rapid rise of urbanization levels and higher global population rates. UNICEF stated several water scarcity facts highlighting how critical water scarcity concern is. These facts include that by early 2025, half of the world's population can be living with water scarcity, while by 2030 700 million people globally can be addressed with severe water scarcity, and by 2040 around 1 in every 3 children will be living in an area with extreme water stress as mentioned by the UNICEF [1].

Sustainable Development Goals (SDG) #6 (Clean Water and Sanitation) focuses on the availability of fresh drinking water and clean sanitized water for daily use, and SDG #11 (Sustainable Cities and Communities) ensures that human settlings are sustainable and part of their settling is water availability. These two goals are the main foundational focus of this paper. The SDGs are studied in line with the water treatment technologies that evolved over years with an objective of providing accessible and cost-effective greywater treatment methods supporting in reusing of greywater in landscaping and toilet flushing mainly among other usages, while applying a novel cradle-to-cradle (C2C) sustainable approach for wastewater treatment.

Wastewater is known as the water produced after use; it is divided into greywater and blackwater. Wastewater is considered as important resource for treatment that has many re-uses like toilet flushing and irrigation. The purpose of treating wastewater is to conserve the reliance on freshwater as a water source hence, supporting the global water scarcity concern.

2. Definition of Greywater

Greywater is wastewater produced from buildings and households that excludes toilets; it is a valuable resource for water treatment as it contributes to approximately 75% of the produced wastewater in households. Greywater also has low levels of toxicity, organics, turbidity, and suspended solids when compared with blackwater which includes fecal coliforms [2]. The decision of which greywater treatment method to use will rely on the criteria and quality of the produced greywater from households as it differs from one person's usage to another, and it can even vary along the daily use of the same person. Greywater is further segmented to light grey water which doesn't include laundry, kitchen sink, and cooking stream. Light greywater usually has lower organics contamination and fewer detergents ingredients than heavy greywater which accounts for laundry and kitchen sinks.

Figure 1 presents the percentage division of household greywater showing

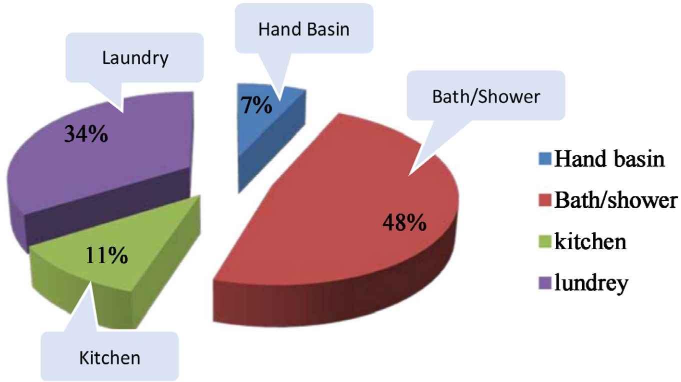

Figure 1. Household greywater source percentages [4].

that bath sinks and showers have the highest effluent greywater percentage followed by laundry, then kitchen, and finally hand basins. Understanding the domestic effluent greywater source percentage will support further understanding of the composition, ingredients and quality of the collected greywater. Hence, the greywater treatment method and parameters for reuse will be considered.

Greywater treatment, no matter if it is heavy greywater or light greywater, is considered to be a valuable treasure and core source for sustainability measures ensuring that the produced water from households is being treated and reused again for toilet flushing, firefighting systems, car wash, irrigation or laundry, and hence, reducing the reliance on fresh water as an initial source of water usage.

3. Greywater Treatment Types

Several greywater treatment technologies and techniques have been introduced and used in previous decades with some of them being more sophisticated than others, some can be costly or hard to implement and maintain, while others are relied on more due to their availability, ease of installation and maintenance and effectiveness. Table 1 briefly summarizes a comparison between different greywater techniques highlighting the pros and cons of each method. Yet, the decision of using a specific treatment method relies on the users' local conditions and availability of resources of treatment and reuse.

From a sustainability standpoint, for social acceptance, economic viability and environmental friendliness, a mix of physical and biological treatment methods along with natural treatment methods could be the best option resulting in better treated greywater quality. Looking at each of the treatment techniques in Table 1, they are categorized under environmental sustainability pillars however, some are hard to implement or maintain like physical treatment methods, and others are costly like chemical treatment methods. Yet, the best to consider for treatment is a mix of physical, biological and natural techniques.

For the physical and biological mix of treatment, sand filter is used in this application. The used sand filter is a standard one with gravel, medium size sand at 60 cm sand bed depth and supernatant water head properly stacked in a PVC pipe. The sand in this sand filter is not mixed with any other packing media

Table 1. Greywater treatment techniques.

	Physical [2] [8]	Chemical [8] [9]	Biological [5] [8]	Natural [10] [11]
Definition	Type of treatment that focuses more on filtration methods or gravity treatment like sedimentation.	Treatment of wastewater by infusing a chemical (like chlorine or hydrogen peroxide) that expedite the disinfection and killing of any organisms.	Type of treatment that relies on bacteria and microbes to breakdown the waste matters included and treat the wastewater.	Ecological self-treatment systems that ensure ecosystem balance relying on natural factors like sunlight and temperature. They are considered as a biological treatment division.
Pros	Partially removing organics, particulate pollutants, nitrogen, and phosphorus nutrients. Also, it reduces the risk of damage for the next treatment phase as it removes any solids mixed in the wastewater used.	Faster disinfection process when compared to other solutions, might produce high amounts of sludge which ensures effective wastewater treatment. The chemicals used are mostly available and not expensive in cost. Sometimes lesser treatment exposure time is used like in the UV treatment stage.	Efficient and cost effective when compared to mechanical systems, and it is the optimal option for organics removal.	More cost-effective and efficient based on the primary treatment method used. Easy to install and in some cases it is considered as a landscape decorative treatment method.
Cons	Inefficient total suspended solids removal. Requires longer time for treatment. Doesn't remove any organic matters or kill any bacteria or pathogens.	With the high amounts of sludge produced, their toxicity levels and volumes need to be considered when disposed. Electricity might be used like in the Ion Exchange or Electrochemical coagulation, hence more cost. Sometimes not all pathogens or microorganisms are removed like in the chlorine treatment and even if TSS is high some can be ineffective like UV.	Cannot be used as a sole treatment method, it is preferred to be used as a secondary treatment after a sedimentation primary treatment. With aerobic/anaerobic treatment, high levels of sludge are produced.	Preferred to be used as a secondary treatment specially in domestic post-treatment usages. Needs high maintenance and can be seasonably reliable based on the plants used.

ingredient; however, in some studies, and depending on the usage, sand filter bed can be mixed with charcoal or sponge from polyurethane foam or ceramic for better greywater treatment efficiency. The ratio of any additional packing material has also been studied to find the best additional material and its ratio mix with sand within the sand filter [5]. Another study mixed the sand with phosphorus adsorbing biotite layer to enhance the effluent treated showing an enhancement in microbes and nutrients [6]. Another study included a layer of sand bed followed by another layer of sand bed mixed with carbonized rubber wood sawdust for wastewater treatment of water contaminated with copper [7]. These are all advancements in the sand filter application that showed enhancement in the effluent greywater quality; however, for this study recommendation based on the influent greywater quality and the expected effluent treated reuse purposes the sand used wasn't mixed with any other ingredient.

For the natural greywater treatment integration with the sand filter, water hyacinth plants are of reference as they are densely populated in rivers that when they outgrow, they can cause water contamination, shadowing higher volumes of water surfaces enriching the production of algae, and affecting the marine life. Nonetheless, if they were cropped to be disposed of, they are hard to biodegrade hence impacting solid waste management. The best optimization for their use is to integrate as a natural greywater treatment method in series with sand filters.

4. C2C for Wastewater Management

After considering the needed greywater treatment technique, it is essential to ensure that it is aligned in application with a net zero wastewater approach applying cradle to cradle concept for sustainability measures. Figure 2 reflects on the primary C2C approach available for solid waste management, reflecting how the C2C closed cycle works to conserve waste starting with the extraction of material from its source. The extracted raw materials are delivered to manufacturing and processing where they are shaped into the needed end product. Afterwards, the end product is packaged, transported and delivered to the end user. After the product is used by the consumer, the used product can either go back into the extraction of raw materials step for on-site recycling; and through that, a closed loop of product use, optimization and reuse is achieved meeting the C2C concept. Or, if the used product cannot be recycled on-site, it will be delivered for off-site recycling.

Referring to C2C for solid waste management approach concept, a novel approach of a fully closed and sustainable wastewater cycle is designed. Figure 3 proposed the idea aiming at reducing the reliance on water at the source within a community, and accordingly reducing the energy consumption. The water source

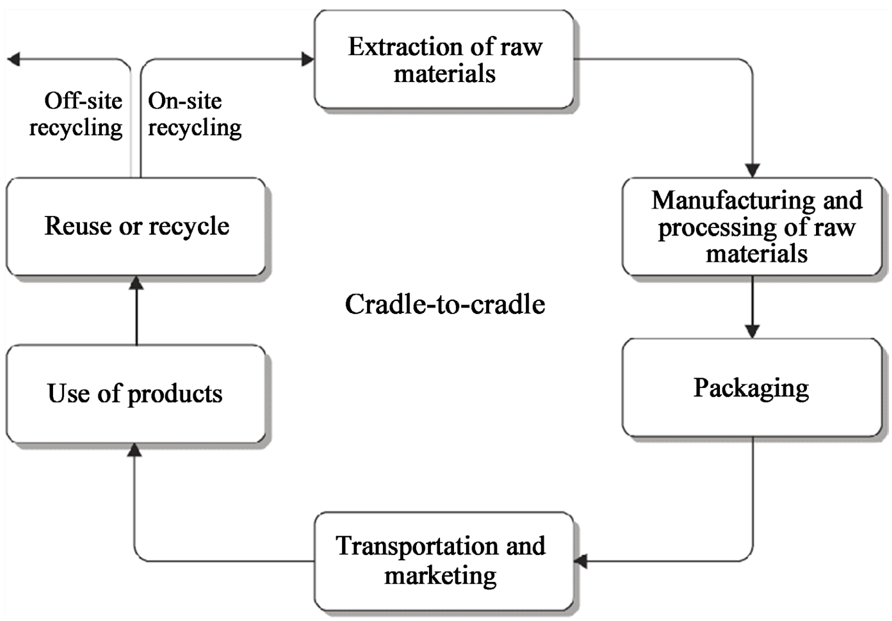

Figure 2. C2C approach for solid waste management [12].

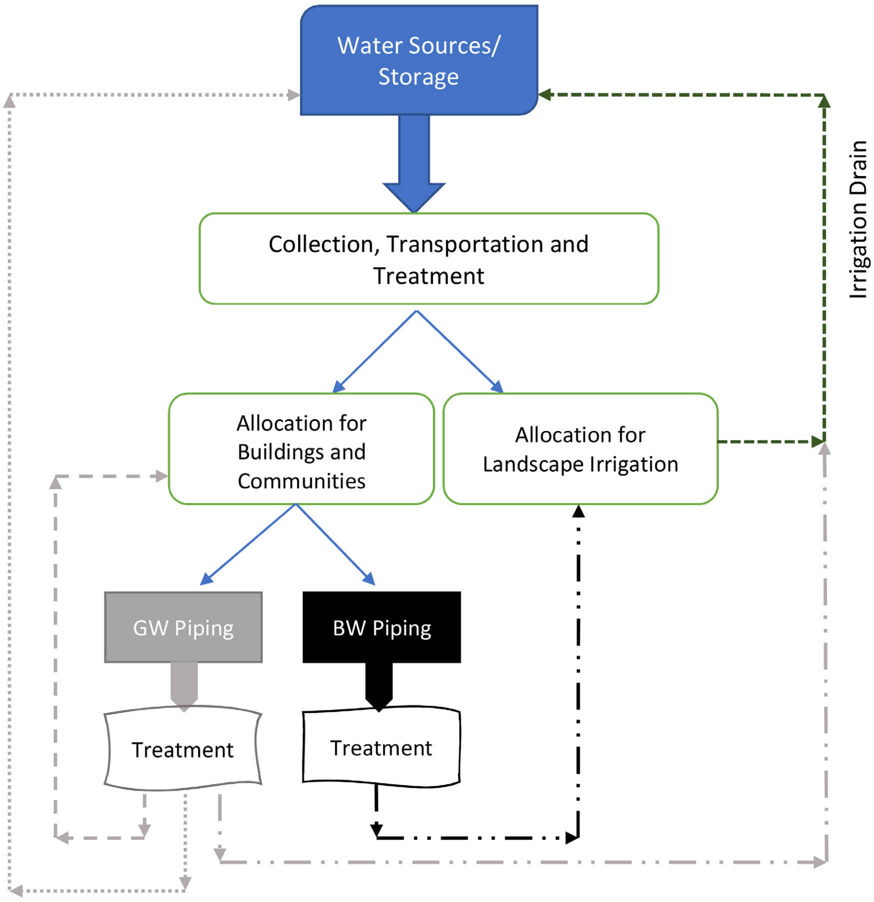

Figure 3. C2C for net zero water approach for waste water in urban communities.

in Figure 3 is initially fresh water from the River or Lakes, the municipality, or other occasional water sources like rainfall. The water is collected and transported to the municipality for initial treatment ensuring safe water effluent quality for citizens use. Afterwards, the treated water shall be delivered through piping systems to the nearby communities for use. Inside the community, the received initially treated water is collected and allocated for distribution within buildings, malls, parks, and on-community facilities through the piping system.

After its domestic use, collecting the effluent wastewater within the building and facilities is next. A conceptual proposal is to separate the wastewater piping system to collect greywater separately from blackwater. This piping division proposal is presented in Figure 3 and Figure 4 for community infrastructure to support wastewater separation from the source easily. The main focus of treatment relies on effluent greywater. The effluent greywater is collected in storage tanks to be treated. The storage tanks can be centralized on the community scale or decentralized on a cluster of building scales. Then the collected effluent greywater will be treated on-site or on-community, either undergoing centralized treatment on the community scale or decentralized treatment on a cluster of buildings scale. The on-community-treated greywater effluent will re-enter the cycle again as part of the water source. This treated greywater can be used in toilet flushing, firefighting systems, or for irrigation of landscapes. In the case of landscape irrigation, the drain will be added to the water source with no treatment required at this step because the plant drain water from irrigation is considered initially treatment through the plant's root. The blackwater piping will direct the blackwater to the WWTP off-community.

Assessing the proposed novel approach for net zero water and wastewater application as per the sustainability pillars of being economically viable, socially acceptable, and environmentally friendly; the proposed concept applies for environmental purposes since at the end of the day it is focused on optimizing the treated greywater reuse while saving the main initial water source. From a social acceptance, this proposal is easy to implement on community and city scales, it can be integrated with uplifted infrastructure while applying treatment techniques that are easy to apply and maintain. Lastly, from a cost-effective, even though the initial cost will relatively high considering separate piping system inclusion for GW and other for BW, collection and treatment however, the water savings and reductions on bills will be noticed shortly while on the long-term, energy savings, water saving and other initially included costs will pay back with a sustainable city or community while saving the main natural resource that is being abused, that is water.

Figure 4 is a schematic proposal highlighting the need of piping systems separation for greywater and blackwater collection where the collected blackwater will be sent to the WWTP placed outside the community. However, the collected greywater will be sustainably treated on community using a sand filter as a primary treatment step followed by aquatic hyacinth plants as secondary treatment

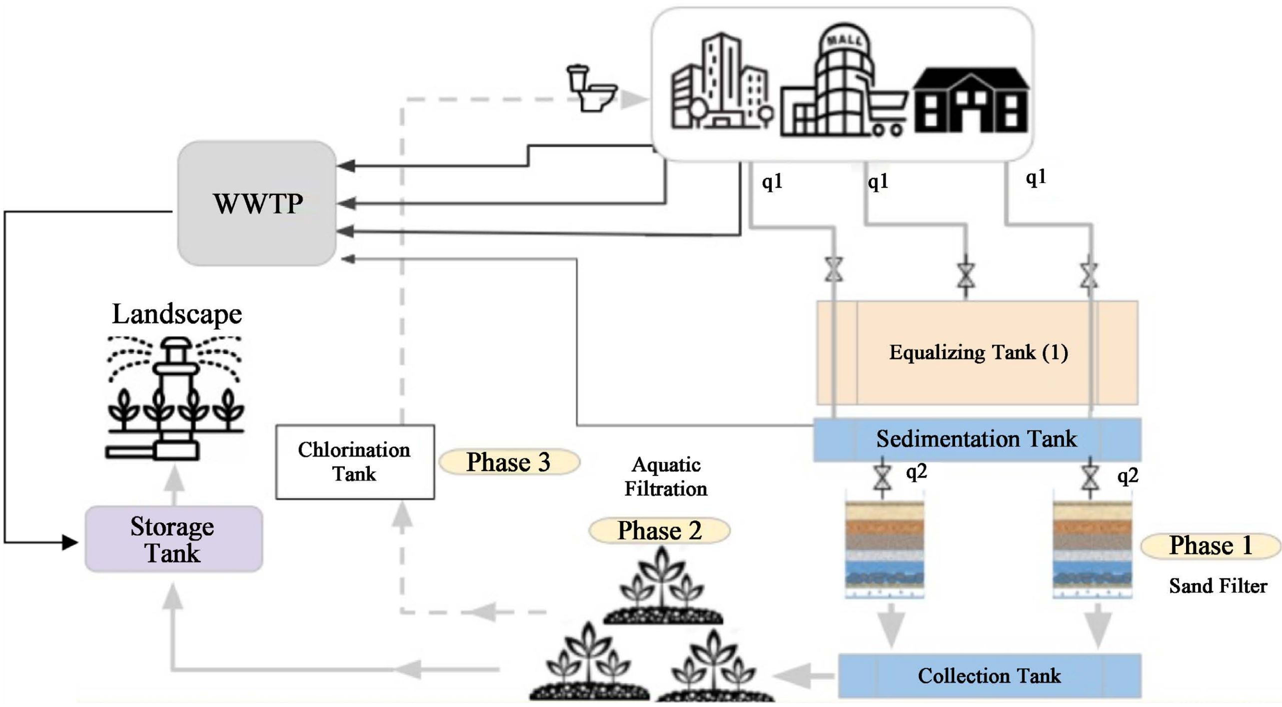

Figure 4. Community schematic for WWT applying net zero concept.

stage in an in-series treatment integration. The process of the greywater collection will be decentralized on a cluster of buildings/a zone for smaller storage tanks dimension and space, while also, decreasing the overall treatment system load. The collected greywater will be collected in an equalizing tank along the day to equalize the collected greywater parameters then the collected greywater will pass onto the sedimentation tank to allow the suspended solids to settle, and then the greywater will pass through the sand filter following a downward flow where greywater influent is added into the sand filter from the top allowing it to pass down through the sand bed for filtration. After the sand filter treatment, the treated greywater passes through aquatic water hyacinth plants for further treatment ensuring that the final effluent treated greywater is of the needed quality. A percentage of the effluent-treated greywater can undergo a third treatment step, if needed, for chlorination for toilet flushing and the remaining percentage will be collected in a storage tank to be used for landscape irrigation as scheduled. **Figure 4** is an implementation schematic for the C2C for wastewater management discussed in **Figure 3**.

5. Conclusion

As urbanization levels are increasing annually due to citizens moving from rural communities to urban areas seeking better lifestyle, the demand for the existing resources has increased, leading to a pressurized level of resources, in which water is no exception to that. Hence, the need to have a conceptual sustainable greywater treatment strategy with a slight modification in the buildings or communities' piping infrastructure is highlighted in this paper. The purpose is to support reducing the reliance on freshwater for our daily needs, while also, reducing the amount of wastewater diverted in wastewater treatment plants. Hence, the development of a sustainable net zero water technique for greywater treatment is proposed in this paper by introducing a novel C2C approach for wastewater management for domestic reuse; while also, meeting the sustainability pillars of being cost-effective, easy to implement, and environmentally friendly. This is met through the proposed sustainable greywater treatment system of an in-series integration of sand filter, which is a mix of physical and biological treatment, and aquatic filtration, which is a natural treatment method.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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